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Authors
Ulibarri, N
Garcia, NE

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Comparing Complexity in Watershed Governance: The Case of California

Nicola Ulibarri [1,*] and Nataly Escobedo Garcia [2]

[1] Department of Urban Planning & Public Policy, University of California, Irvine, CA 92697, USA
[2] School of Social Ecology, University of California, Irvine, CA 92697, USA; nrescobe@uci.edu
* Correspondence: ulibarri@uci.edu; Tel.: +1-949-824-6484

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Abstract: Environmental governance scholars argue that optimal environmental performance can be achieved by matching the scale of governance to the scale of the resource being managed. In the case of water, this means managing at the scale of the watershed. However, many watersheds lack a single watershed-scale organization with authority over all water resources and instead rely on cross-jurisdiction coordination or collaboration among diverse organizations. To understand what "watershed governance" looks like fully, this paper maps organizations with rights to use, regulate, or manage water in four subwatersheds in California (the American, Cosumnes, and Kings Rivers in the Sacramento-San Joaquin watershed and the Shasta River in the Klamath watershed). We assemble datasets of water organizations, water rights holders, and water management plans and use content analysis and social network analysis to explore what water management looks like in the absence of a single basin authority. We describe the institutional complexity that exists in each watershed, compare the physical and institutional interconnections between actors in the watersheds, and then ask to what extent these connections map onto watershed boundaries. We find that the ways in which water management is complex takes very different forms across the four watersheds, despite their being located in a similar political, social, and geographic context. Each watershed has drastically different numbers of actors and uses a very different mix of water sources. We also see very different levels of coordination between actors in each watershed. Given these differences, we then discuss how the institutional reforms needed to create watershed-scale management are unique for each watershed. By building a stronger comparative understanding of what watershed governance actually entails, this work aims to build more thoughtful recommendations for building institutional fit.

Keywords: watershed governance; watershed management; complexity; groundwater; California

1. Introduction

Water is seen to be the quintessential wicked problem [1–4]. It is an essential resource for human survival, so its management or control has been central to the development of civilizations over human history [5]. Scientifically, the spatial and temporal distribution of water is highly variable and nonstationary, leading to uncertainty about when and where it will be available [6,7]. This problem is worsened for the harder-to-measure parts of the hydrological cycle like groundwater [8] and by the increasing variability of temperature and precipitation under climate change [9,10]. Socially, water is incredibly contentious, with numerous competing views on how water should be managed [11,12].

Besides the wickedness inherent in water itself, historical institutional arrangements have made managing water inherently multilevel and complex [13]. In any watershed, there are numerous actors operating at multiple levels [14,15], and these actors all have distinct and at times competing goals [16]. Theories like the food-water-energy nexus [17,18] point out that water management decisions inextricably affect and are affected by the management of other resources, adding to the perceived complexity of water governance.

The common suggestion to overcome and/or manage this complexity is to manage water at the scale of the watershed [19,20]. Watershed governance extends from the idea that resources should be managed at the scale that they exist, thereby improving institutional fit [21,22]. In practice, this means either making new watershed-scale institutions and/or encouraging collaboration or coordination between the multiple actors that manage water within the watershed [15,23,24]. Scholars have criticized the watershed approach, noting that it may not always be the most appropriate scale [20] and can complicate management because it adds a new layer to already complex governance systems [15]. However, the watershed management approach remains the consensual norm among policy makers and water managers, with prominent examples like the European Union's Water Framework Directive mandating basin-scale management.

This paper assesses the physical and institutional characteristics of water management in four watersheds in the United States (U.S.), the state of California, in order to understand what it would take to achieve watershed-scale governance. We focus on California partly because it lacks any explicit watershed-scale management. In 2002, the state initiated an Integrated Regional Water Management Planning process, which aimed to create collaborative groups at the scale of the hydrological region, but these local groups fragmented to create five times as many planning groups ultimately [14,23], very few of which matched the watershed boundaries. We ask, in the absence of a "basin authority": What does water management look like in four relatively small watersheds? We describe the institutional complexity that exists in each watershed, compare the physical and institutional interconnections between actors in the watersheds, and then ask to what extent these connections map onto watershed boundaries.

2. Literature Review

2.1. Complexity and Fragmentation in Water Resource Management

Few people would dispute that managing water is complex. In many contexts, and especially the United States, layers of individual organizations have emerged that each manage different parts of the hydrological system. For instance, separate organizations are responsible for allocating water quantity versus regulating and protecting water quality; separate organizations responsible for water quantity and water quality exist at the local, state, and federal levels. At the local level, many jurisdictions have separate utilities providing drinking water, cleaning wastewater, and managing stormwater, even in places where these separate functions share the same infrastructure. Numerous bordering (and sometimes overlapping) jurisdictions or utilities may provide identical services in a relatively small geographic area [23]. Finally, there are numerous other actors that influence parts of the water system, including the land management agencies that oversee the terrain where this water collects, the fish and wildlife organizations that protect the aquatic habitat, and the numerous non-governmental organizations who play important roles in voicing how water should be managed and for whom.

Depending on how you view this institutional complexity, it can be a blessing or a curse. Traditional views of government fragmentation note that having all of these competing players increases transaction costs and reduces the efficiency of service provision [25]. Fragmentation also leads to uneven application of policies or management interventions across a landscape [26]. As Wallis and Ison wrote on water governance, "The sheer number and diversity of institutional arrangements can... constrain effective NRM (natural resource management) governance, and can have major implications for governance innovation including stakeholder engagement and concerted action among a group of stakeholders" [15] (p. 4082). Conversely, approaches from the schools of complex adaptive systems and polycentricity would argue that building redundancy into a system improves its performance [27–29]. By modularizing a system, risk is spread across numerous units [30], so in the instance that part of the system fails, the resource as a whole (and the people that depend on it) are still intact.

Whichever perspective a scholar adopts, managing this system is generally seen to be challenging [1,13] relative to many other resources or service delivery problems. Managing in the face of complexity requires not only gathering information and applying it to a problem, but also prioritizing across competing measures, resolving conflicts, deciding under uncertainty, and being flexible when things do not work as planned [31].

2.2. Watershed-Scale Management

Watershed-scale management is often touted as a solution to the complexity of water governance [19,20]. A watershed is defined as the land area that drains to a specific location, often a lake, river confluence, or estuary. The idea of the watershed as an organizing concept for water management has a long history, from river basins acting as functional units in Third-Century China [32] to John Wesley Powell's proposal that the Western U.S. states should be created around rivers [33]. In more recent years, its popularity has spread, particularly with the advancement of "Integrated Water Resource Management" in the 1990s [32]. Indeed, Davidson and de Loë called the watershed the "de facto ideal boundary" among water managers and practitioners [20] (p. 367). The perceived effectiveness of this idea was highlighted in a recent article on Powell's proposal, which argued that "Powell's foresight [to create watershed-based states] might have prevented the 1930s dust bowl and perhaps, today's water scarcities" [34].

The arguments for watershed-scale management are fairly straightforward. Matching the jurisdictional boundaries of a governance institution to the boundaries of the resource it manages helps to ensure that the resource is managed as a consistent unit, achieving what is called "institutional fit" [21]. The idea is that a forest, for instance, will be most effectively managed if a single institution has jurisdiction over the entire forest, rather than having multiple institutions responsible for different portions of the forest. In the case of water, scholars argue that the best unit to achieve institutional fit is the watershed scale [35,36]. First, as a distinct hydrological unit, the boundary of the watershed can be mapped more easily than other resources, and they (usually) do not change on timescales perceptible to humans [20,37–40], making the watershed seem to be a relatively straightforward boundary. Second, water sources and uses in a watershed are seen to be interrelated [41–45]. Third, given the problems of institutional fragmentation across parts of a water system [23,41], aggregating up to the watershed is seen to be an effective way of overcoming this fragmentation [44,45]. In other contexts, watershed-scale governance is favorable because of the ability to govern resources locally [46–48]. Finally, besides these more technical rationales, Cohen argued that the concept of a watershed is "both cohesive enough to travel among different epistemic communities, and plastic enough to be interpreted and used differently within them" [49] (p. 2207); in other words, that the watershed concept is popular simply because it can signify whatever is useful for a particular context or group of people.

Despite its widespread use, there is still much debate about whether using watersheds as an organizing concept is beneficial. First, the boundary itself may not be as straightforward to delineate as is commonly assumed. A watershed is the area of land that drains to a particular point; while it is commonly assumed that the point will be an obvious water body (e.g., a lake or an ocean), that is not inevitable [41,50], and smaller units can easily be justified. In some environments, the physical boundaries of a watershed may shift on fairly short timescales. While watershed management often pays close attention to the interrelation of land and water management, there has been less attention on groundwater management as part of the overall watershed [46]. In settings where groundwater feeds or is fed by surface water, managing just the surface water could lead to unintended side-effects [50].

Second, creating basin-scale organizations does not erase existing political boundaries. This creates several challenges. From an accountability perspective, it may be unclear who is ultimately responsible for decisions made about the watershed or portions therein [50]. It also can increase complexity, as layering new institutions can simply add to the fragmentation and create new coordination needs and associated transaction costs and administrative burden [15]. The watershed concept also assumes "that citizens recognize and engage at the watershed scale" [20], which is not necessarily true.

Third, the problems faced by a watershed often do not match watershed boundaries. Problems may arise from outside the watershed, as in the case of invasive species; likewise, problems emerging from within the watershed may affect other locations [20]; or the watershed may not capture all important areas of a related resource (e.g., ecosystems spread across multiple watersheds or portions of multiple watersheds) [50].

Finally, it is important to remember that the scale at which water is managed is not inherent. Choosing to manage at the local, watershed, national, or other scale is a political act with political ramifications [41,49,51]. This choice matters substantively for democratic governance, as well as the efficiency and equity of decision-making [51–54].

3. Materials and Methods

This research used a comparative case study approach to describe the physical and institutional setting in watersheds that lack a central basin authority. We focused on subwatersheds, defined as a smaller river that drains into a larger river. (In the parlance of the U.S. Geological Survey, these are 8-digit Hydrologic Unit Codes, nested within larger 6-digit codes [55]). Subwatersheds—rather than entire watersheds from source to ocean—serve as a critical case [56], as they are relatively small (in size and population) and should therefore be simpler than a full watershed.

3.1. Case Setting

California's Central Valley, stretching from the Cascade Range in the north, the Sierra Nevada to the east, the Tehachapi Mountains to the south, and the Coast Ranges and San Francisco Bay to the west, covers over 200,000 acres and is known for agricultural production. Using less than 1% of U.S. farmland, the Central Valley supplies 8% of U.S. agricultural output (by value) and produces about 25% of the country's food, including 40% of the country's fruits, nuts, and other table foods. Agricultural production in the Central Valley has an annual value of $17 billion. Additionally, about 20% of the Nation's groundwater demand is supplied from pumping Central Valley aquifers, making it the second most-pumped aquifer system in the U.S. [57].

Besides agriculture, the Central Valley plays numerous other key roles in supporting human and environmental wellbeing. The mountains and foothills that serve as the source of the water are prime recreational destinations for hiking, backpacking, skiing, and whitewater boating. The Sacramento and San Joaquin Rivers were home to sizeable runs of salmon and steelhead (most of which are now endangered), and the rivers and floodplains are critical for their restoration. Finally, the rivers discharge into the San Francisco Bay-Delta, the largest estuary on the Pacific Coast.

For this study, we focused on four small watersheds within the Central Valley: the drainage basins for the Shasta, American, Cosumnes, and Kings Rivers (Figure 1). Each is a subwatershed of a much larger river: the Sacramento, San Joaquin, or Klamath. (Technically, as a tributary of the Klamath River, the Shasta River is not in the Central Valley.) These watersheds were selected for variation in a variety of hydrological and socioeconomic characteristics (Table 1). The American and Kings Rivers are both quite large, in terms of watershed area, discharge, and population, while the Shasta and Cosumnes are relatively small. The watersheds vary in the relative importance of surface versus groundwater as water supply, as well as in their dependence on snowpack versus rainfall. The watersheds also span from relatively poor (including predominantly white and predominantly nonwhite) to quite wealthy regions. Finally, in all four watersheds, agriculture is a dominant industry, but tourism also plays an important role.

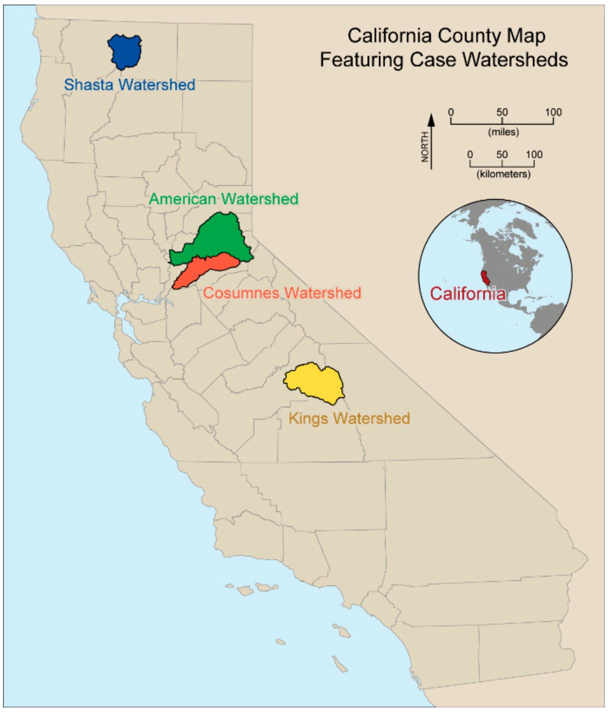

Figure 1. Map of the case study watersheds.

Table 1. Watershed characteristics.

	Shasta	American	Cosumnes	Kings
Larger watershed	Klamath	Sacramento	Mokelumne (tributary to San Joaquin)	San Joaquin, Tulare Lake
Counties	Siskiyou	Placer, El Dorado, Sacramento	Amador, El Dorado, Sacramento	Fresno, Kings, Tulare
River length (km)	93.3	191.5	84.4	213.9
Watershed area (km^2)	2072	5568	1875	3999
Annual mean discharge (m^3/s)	5.1	104.1	14.0	64.7
Mean annual runoff (m^3)	1.63×10^{11}	3.30×10^{12}	4.42×10^{11}	2.22×10^{12}
Population	44,900	1,986,369		1,522,812
% white, non-Hispanic [1]	79.5%	56.8%		32.7%
Median household income (US$)	$40,884	$69,062		$47,781
% below poverty line	20.7%	14.5%		25.4%

Note: Demographic characteristics aggregated by county (larger area than the watershed) from the 2017 American Community Survey 5-year estimates [58]. American and Cosumnes are aggregated because they share two counties. Watershed data from the USGS National Water Information Service [59].[1] Percent white, non-Hispanic is a common metric for racial and ethnic diversity in the U.S.

3.2. Data and Analysis

This study drew on a variety of Internet and document-based data sources. To compile a list of actors from each watershed, we used the California Department of Water Resources (DWR)'s water management planning tool [60] and lists of special districts from the California Public Utilities Commission, water districts from the California DWR [61], and water agencies from the Association of California Water Agencies [62]. In many instances, the organizations were listed by county, not watershed, so we used maps and information on water sources/service area to infer whether an organization was active and/or located in a particular watershed. Water rights data were obtained from eWRIMS (the Electronic Water Rights Information Management System) [63].

We also obtained a variety of plans that influenced how water was or should be managed in each watershed (Table 2). These management plans covered a variety of jurisdictions and scales, from municipal water supply to federal land management to regional water coordination. The sample was as comprehensive as possible and included all state or federally mandated plans that had a link to water within each watershed.

Table 2. Plans included in the analysis.

Plan Type	Author Type	Shasta	American	Cosumnes	Kings
Agricultural Water Management Plan	Irrigation District		2		7
County General Plan	County	1	3	1	3
Federal Land Policy & Management Plan	Bureau of Land Management		1	1	2
Integrated Regional Water Management Plan	IRWM Region	1	2	1	2
National Forest Management Plan	US Forest Service	1	1		2
Natural and Cultural Resource Management Plan	National Park Service				1
Urban Water Management Plan	Municipal Water Utility	1	11	2	6

The plans were coded using QSR International's NVivo 12 qualitative analysis software (Melbourne, Australia). We assessed where different organizations obtained water, as well as how they discussed their interconnection with other parts of the watershed and/or other actors in the watershed. Additionally, the plans listed other organizations that they interacted with during plan preparation, including coordination regarding water supply and demand, plan preparation, and of what regional networks they were members. We culled this information to visualize water supply, coordination, and outreach networks. Network analysis was conducted using the tidygraph package in R [64], with the figures restructured to enhance clarity and meaning [65].

4. Results

4.1. Who Are the Actors?

We first assessed the distribution of organizations that managed water in each watershed (Table 3). This included municipal and commercial water utilities (including counties and cities that provided water directly), community service districts (utilities that provided service in unincorporated areas), irrigation districts, tribes, electrical utilities who owned hydropower projects, groundwater management agencies, as well as federal and state agencies with explicit activities occurring in the watershed. For state and federal agencies, we included only those organizations with landholdings, water rights, or active projects in the watershed. In other words, this table did not include federal, statewide, or regional regulatory agencies, such as the U.S. Fish & Wildlife Service or the State Water Resources Control Board, unless they had unique powers or activities in the watershed. Additionally, there was no centralized source of information on nongovernmental organization (NGO) activity, so we opted to omit them from the table rather than knowingly undercounting their presence.

Table 3 shows that even the small watersheds (Shasta and Cosumnes) had a diverse mix of active organizations, while the larger American and Kings basins had numerous organizations all making decisions about water. The American watershed had a high proportion of municipal water agencies; the Cosumnes had equal numbers of water agencies and community services districts (which served rural areas); and the Kings had roughly an equal distribution between water agencies, cities that provided water directly, and irrigation districts.

In these systems, we did not see any organizations whose jurisdictional extent matched the boundaries of the watershed. Most of the organizations in Table 3 operated at fairly small scales, i.e., the service area for a city, irrigation district, or occasionally county. The Joint Powers Authorities included several regional organizations, such as the Kings Basin Water Authority, but none of these regional organizations mapped directly into the boundaries of the watershed, instead focusing on just the upper or lower portions of the watershed.

Table 3. Water management organizations by watershed.

Organization Type	Shasta	American	Cosumnes	Kings
Water Providers				
City		5		9
Community Services District	1	4	6	5
County		1		2
Irrigation District	3	4	3	11
Public Utility District		3	1	1
Water Agency		20	7	12
Other Organizations that Manage Water				
Electric Utility		2		1
Federal Agency	2	3	1	4
Groundwater Sustainability Agency	1	3	2	5
Joint Powers Authority	1	3	1	3
State Agency	1	2		
Tribe	1	2	4	2
Other	5	2	4	6
Total	15	54	29	59

Note: A few organizations were water providers that also served as groundwater sustainability agencies. In these instances (n = 5), we only list the water provider type.

Authority over water use was also exercised through legal water rights. Table 4 shows the number of individuals or organizations holding different types of water rights (this was distinct from the total number of water rights, as many organizations held multiple permits). Regarding the types of rights, adjudicated rights were assigned by a judge; appropriative rights were a permitted right to use water for any beneficial use; federal claims were federally-held water rights (including tribal rights and rights associated with federal land); and a registration was a streamlined right for "a small domestic use, a small irrigation use, (or) for a livestock stockpond subject to prior rights" (CA Water Code §1228.1). A statement of diversion and use was any diversion not covered by another permit or registration, for instance a claim from a riparian rights holder. Shasta, Cosumnes, and Kings each had fairly small numbers of individual water rights holders, with a mix of appropriative, domestic, diversion, and stockpond rights. In contrast, American had ten times as many individual water rights holders as the other watersheds, representing all possible types of water rights.

Table 4. Count of water rights by watershed.

Water Right Type	Shasta	American	Cosumnes	Kings	Total
Adjudicated	1				1
Appropriative	14	393	13	28	443
Federal Claims		3		2	5
Registration Domestic	1	26		1	28
Registration Livestock		2			2
Registration Stockpond		26		21	47
Statement of Diversion and Use	16	112	30	14	170
Total	32	562	43	66	703

Note: Cancelled, inactive, rejected, and revoked rights not shown.

The relative volume of appropriated water rights could give insight into who the important players were in each watershed and how power was distributed among them. Figure 2 shows the allocations of the 10 largest water rights holders by watershed. The x-axis indicates the total volume of allocated water rights as a percent of the mean annual runoff (from Table 1). Shasta and Cosumnes both had a mix of small and medium water rights holders, including irrigation districts, individual farms, water utilities, and environmental interests (the Nature Conservancy and the California Department of Fish and Wildlife). In the American, the largest allocations went predominantly to large water utilities (including the U.S. Bureau of Reclamation (USBR)) and a few hydropower-generating electric utilities. The Kings River was dominated by three organizations—the Kings River Water Association, Pacific Gas & Electric (a hydropower utility), and the Kings River Conservation District—who each had water rights five orders of magnitude larger than any other organization in the watershed.

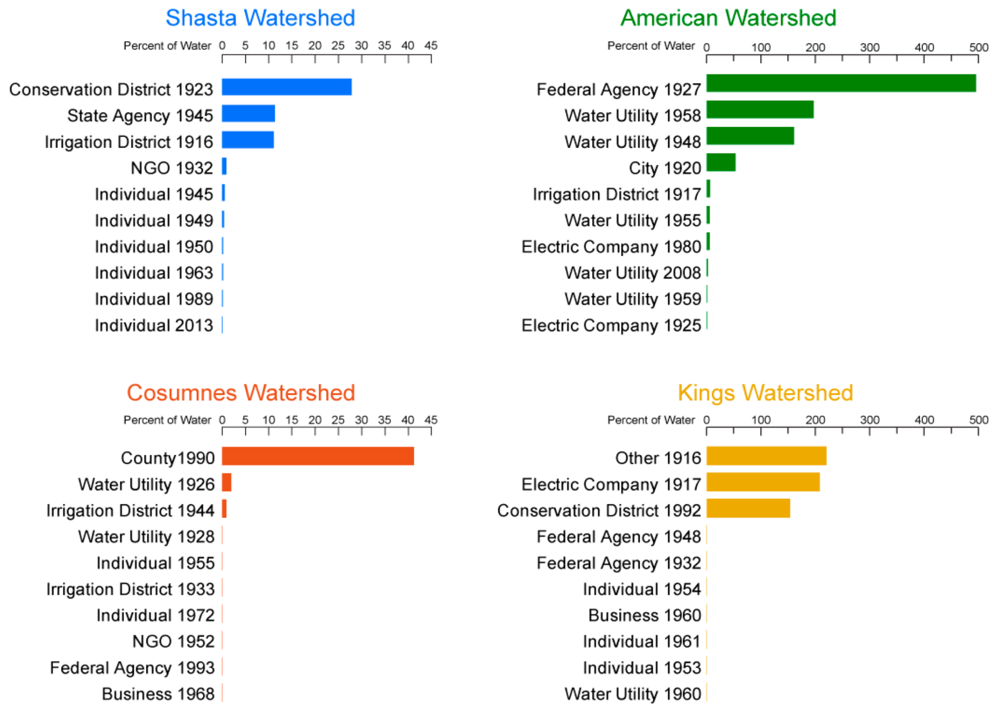

Figure 2. Volumes allocated, organization type, and year of permit for the 10 largest water rights holders by watershed. The x-axis indicates the total volume of allocated water rights as a percent of the mean annual runoff; the scale varies by watershed. Note that some organizations hold rights larger than the average annual runoff.

As a prior appropriation state, users with the oldest water right had priority to divert water before users with newer rights. In Shasta, the largest volumes were held by the organizations with the oldest rights. In the American, the oldest rights were of medium volume; these would be filled before the three largest water rights holders received their allocation. In Cosumnes, the largest user held a relatively junior right, followed by more senior individuals. Lastly, in Kings, the two largest water rights holders also held the most senior rights.

4.2. How Are Actors Physically Interconnected?

From a purely hydrological perspective, all actors within a watershed are interconnected. Water originates as snow or rainfall in the mountains, then moves down toward the valley floor, where it interacts (either gaining or losing) with underlying aquifers. Any decision to divert water from a river, extract it from the ground, or return water to the river/aquifer thus affects all downstream or down-gradient actors.

However, some actors are more directly reliant on one another through physical sharing of water. Figure 3 summarizes the inter-organizational water sharing that occurred in each watershed. It depicts all water supplies listed in each organization's plan, including both direct withdrawals from rivers or aquifers and supplies purchased from another organization. For context, the Central Valley Project (CVP), run by the U.S. Bureau of Reclamation (USBR), is an extensive system of dams and canals that draws water from multiple watersheds and supplies water to over 250 contractors throughout California.

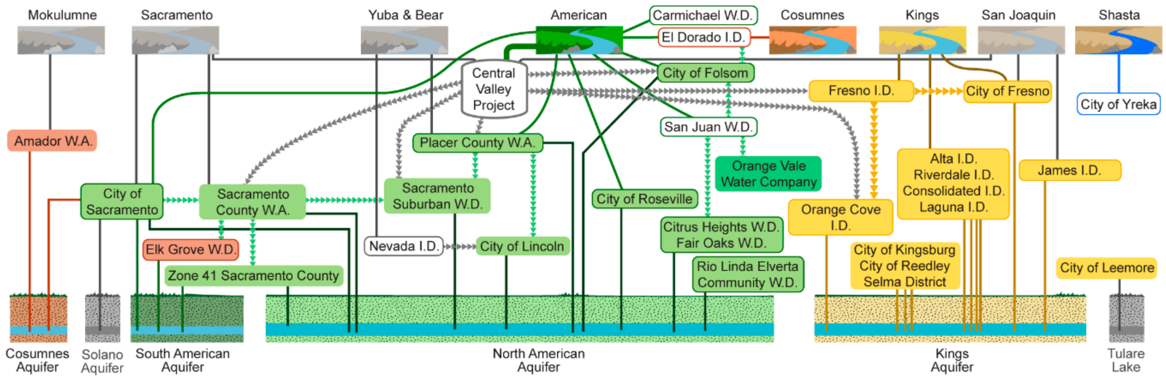

Figure 3. The water supply network, including surface and groundwater sources, in the four case study watersheds. Rivers are listed on the top, and aquifers are along the bottom. Shasta organizations are indicated by blue, American by green, Cosumnes by orange, and Kings by yellow. Solid lines indicate direct withdrawals, and dashed arrows indicate water purchases. Boxes with outlines indicate surface water use; shaded boxes indicate groundwater use. "I.D." = Irrigation District; "W.D." = Water District; "W.A." = Water Agency.

In the Kings watershed (yellow), there was an intense reliance on groundwater, as every water organization assessed used the Kings aquifer for at least a portion of its water supply. Out of the six Urban Water Management Plans (UWMP) reviewed for Kings, five stated that they relied solely on groundwater. The City of Fresno was the only exception, purchasing surface water from the Kings River through a contract with Fresno Irrigation District and CVP water (sourced from outside the Kings watershed) through a contract with USBR. The rest of its water came from a network of 260 wells in the Kings Aquifer. Irrigation districts in the Kings watershed had more diverse water portfolios, with conjunctive use of surface and groundwater resources being a common practice. Only one of seven Agricultural Water Management Plans (AWMPs) used solely groundwater. Finally, only three Kings organizations assessed purchase water from another organization.

In the American watershed (green), organizations tended to have more diverse water portfolios than in the Kings, with most organizations relying on both surface and groundwater. Indeed, only one organization (Rio Linda Elverta Lina Community Water District) relied solely on groundwater, and three (of 14 total) relied solely on surface water. The remaining 10 American watershed organizations used both, often drawing on multiple sources of each.

There was also far more inter-organization purchasing in the American watershed, with small and large districts holding contracts with large water suppliers like the USBR (which operates Folsom Dam as part of the CVP), San Juan Water District (SJWD), and Placer County Water Agency (PCWA). Most (nine of 14) organizations in the American watershed purchased water from one or more of these large suppliers. Purchased water occasionally formed an organization's entire supply (e.g., Orange Vale Water Company), but most organizations supplemented with groundwater and/or surface water obtained directly from the river.

Of the large wholesalers in the American, SJWD relied entirely on the American River for its supply, from both directly held water rights and contracts to purchase water from PCWA and USBR. PCWA received most of its surface water from the American River, but also had contracts with USBR to CVP water and with Pacific Gas & Electric to water from the neighboring Yuba and Bear Rivers. PCWA also used groundwater in case of dry conditions if their surface water supplies were limited.

Water supplies in the Cosumnes (orange) came from a mix of surface and groundwater, with one organization purchasing water from another. For the one Shasta watershed organization (blue) assessed, the entire water supply came directly from the Shasta River.

4.3. How Are Actors Institutionally Interconnected?

The previous section showed that many organizations were physically connected through shared water sources. Here, we assess whether the institutions and interactions between these organizations mirror this physical sharing.

4.3.1. Regional Networks

Within each watershed, there was a variety of water networks that coordinated on various aspects of water management. The first were the Integrated Regional Water Management (IRWM) groups, which were initiated by the state legislature in 2002. These groups aimed to improve water supply security through the development of a shared regional plan for water management [23,24,66]. IRWM regions covered 87% of the state's area and the entirety of the four watersheds assessed in this study. However, the IRWMs' geographic boundaries relative to each watershed boundaries varied substantially. The Shasta River was part of the North Coast IRWM, which covered eight counties in northwest CA; of a long list of affiliated organizations, only a handful came from Siskiyou County. In the other three watersheds, the headwater portions were managed as part of a larger IRWM region: the Cosumnes-American-Bear-Yuba (CABY) IRWM for the American and Cosumnes Rivers and the Southern Sierra IRWM for the Kings (which covered the Kings and five neighboring watersheds). The valley floors formed standalone IRWMs in the Kings and American watersheds.

The types of organizations involved in each IRWM also varied across watersheds. The North Coast IRWM was large and diverse, with significant representation of water agencies, NGOs, and tribes. The CABY IRWM had a substantial number of both water agencies and NGOs, while the Southern Sierra IRWM had a variety of federal agencies and NGOs, but few water agencies. Finally, the members of the Regional Water Authority (the lower American IRWM) and the Kings Basin Water Authority (the lower Kings IRWM) were both made up of just water agencies, with other organizations listed as "Interested Parties."

Besides the IRWMs, the American and Kings watersheds were home to several other water networks. In the American, the Sacramento Water Forum Agreement was a partnership that aimed to create a more sustainable water supply while protecting riparian and aquatic habitat; almost every water utility identified in the basin was a signatory to the Agreement, as well as several business associations and environmental NGOs. As its name suggests, the Sacramento Groundwater Authority sought to coordinate management of the aquifer underlying the American River (as dictated by the Water Forum Agreement); members included the many water utilities that used this groundwater. In the Kings, the Kings River Water Association was formed to solve water rights disputes and coordinate management along the river; they acted as a water master, contracting water to member agencies. (they were also the largest water rights holder in the watershed (Figure 2).).

4.3.2. Coordination and Outreach Networks

The second substantial form of coordination arose during the development of the many plans about water management. For all the plans in this analysis, there were specific legal/regulatory ways in which the organization developing a plan was meant to interact or coordinate with others. For instance, for the creation of UWMPs, any urban water supplier that relied on a wholesaler for their water supply must provide water use projections to their wholesaler (CA Water Code 10631(j)). Wholesalers also had to provide information to their retailers, including the projected available water supply for sale, which included projections on water availability in average, single, and multiple dry years. In terms of coordination for the creation of UWMPs, CA Water Code 10,620 (d)(2) required urban water suppliers to coordinate with other appropriate agencies in their areas, to the extent practicable; this usually translated to urban water agencies providing a table listing organizations who participated in the UWMP development, commented on a draft, received a copy of the draft or final plan, or were sent a notice of intent that the UWMP was being adopted. Other plan types similarly dictated who should be consulted in gathering data, preparing the plan, and/or disseminating the plan.

Figure 4 maps the coordination networks as mentioned in each coded plan. A link between the authoring organization and another organization was coded if that organization was consulted regarding the planned water demand, provided comments on a draft plan, or otherwise participated in drafting the document. Arrows flow from the organization that was the plan author to organizations with which they coordinated. The figure also lists unconnected organizations: those that were mentioned in the plan, but not as direct coordinators.

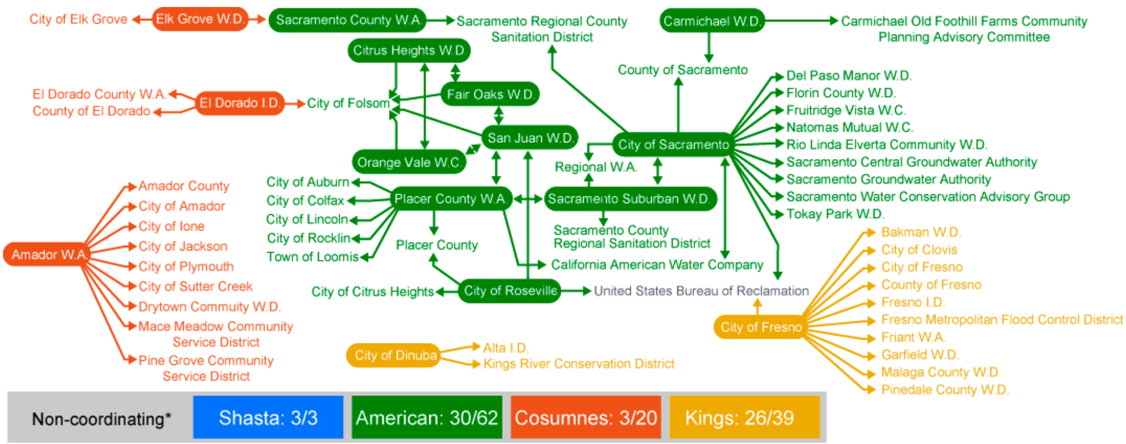

Figure 4. Coordination network by watershed. Non-coordinating organizations (those that are mentioned in a plan, but not as direct coordinators) are listed as a fraction of all organizations mentioned for each watershed. "I.D." = Irrigation District; "W.D." = Water District; "W.A." = Water Agency.

This figure reveals distinct patterns by watershed. In the Shasta (blue), there were very few organizations mentioned overall, and they were not indicated as coordinating. The American (green) had much coordination between organizations. The key hubs were the City of Sacramento, PCWA, and the Sacramento County Water Agency (SCWA). Additionally, there was a tightly interconnected community of utilities that all received water from SJWD, and therefore, all coordinated on demand and supply (as well as plan preparation). Additionally, American organizations (specifically SCWA and the City of Folsom) connected to a handful of organizations in the Cosumnes watershed (orange). The Cosumnes also showed a disconnected component anchored by Amador Water Agency. In the Kings (yellow), the coordination network was driven by the City of Fresno and was entirely unidirectional. Importantly, the networks showed the Kings as being "connected" to the American via the U.S. Bureau of Reclamation (grey). However, this meant simply that they both received water from (and therefore coordinated with) the same organization, but they were unlikely to have actual cross-watershed dialogue through USBR.

Besides coordination, the plans also mentioned the network of organizations that were sent the plan or otherwise notified of its availability. We termed these "outreach", as they likely did not have any influence on the final version of the plan (unlike the coordination network). The number of outreach organizations are listed at the bottom of Figure 4, as a fraction of all organizations mentioned in that watershed's plans. Far more organizations receive information about the plans (outreach) than commented on or otherwise shaped their content. This was particularly true for the Shasta (where the only mentioned interactions were outreach) and the Kings (where only half of listed organizations were in the coordination network). In contrast, almost all Cosumnes organizations interacted through coordination, not just outreach.

4.3.3. Acknowledging the Interconnectivity of Water and Actors

In the absence of direct coordination with other actors, water organizations might also work toward watershed-like management if they acknowledge the interconnectivity of water and actors within their watersheds. By recognizing the shared effects of extracting water from the environment, or that another organization's actions might affect one's water supply, demand, or quality, an organization demonstrates awareness of the common-pool nature of water and is potentially more likely to engage other organizations in co-managing the resource.

Acknowledgment that other people's decisions affect an organization's water availability and vice versa was mostly observed in UWMPs, but unilaterally reflected a one-sided acknowledgment focusing on how the author organization was impacted by others' actions. In the UWMPs, interconnectivity was most visible in the sharing of projected water use between wholesalers and retailers. This information was vital to the creation of UWMPs in order to have an accurate projection of how much water supply would be available for both the supplier and consumer. Acknowledgement of the impact of other actors occurred far more frequently in the American watershed than the others, despite all organizations fundamentally sharing water with other organizations. This was likely because the American had much more exchange of water between organizations. However, the organizations in the Kings and Cosumnes that primarily relied on groundwater gave little to no attention to the impacts or needs of other pumpers in the basin.

In the UWMP sections discussing potential constraints to water supplies, there was also some acknowledgment of other water users. In the American watershed, the plans usually reflected concerns about the availability of water resources in dry years due to reductions in surface water supply pursuant to agreements such as the Water Forum Agreement, USBR Operations Criteria and Plan, and/or CVP Municipal and Industrial Water Shortage Policy. Because these were large scale agreements made between multiple water users, the impacts of these constraints would be felt by anyone under one of those agreements, a more indirect acknowledgement of other users on water availability. In the Kings watershed, discussions of potential constraints were very brief and did not acknowledge other water users; the only constraints that were discussed were needing to pump deeper and/or potential future constraints under the Sustainable Groundwater Management Act. Potential constraints were commonly dismissed with the justification that the Kings was an unadjudicated groundwater basin.

As for acknowledging different parts of the watershed in plans, we saw no evidence of actors located in the upper basin/headwaters discussing water uses or actors downstream, nor actors located in the foothills or valley discussing the upstream sources of their water. Discussions about the connection between groundwater and surface water were fairly mute across plans and watersheds. Because of the intense reliance on groundwater in the Kings watershed, there was no mention of any connection between surface water and groundwater in the UWMPs, with the exception of the City of Fresno. In the AWMPs, there was reference to conjunctive use of surface and groundwater, but often in relation to using water rights and preserving groundwater for times of dry years. Similarly, in the American and Cosumnes watersheds, the majority of plans that did mention a connection between surface and groundwater focused more on preserving groundwater in case of the potential reduction of surface water allocations during dry years.

Finally, as these subwatersheds were all nested within larger river basins, we might expect some discussion of interconnections across watersheds. The IRWMPs often mentioned other IRWM regions. For example, all IRWMPs had a section in which they discussed neighboring regions and gave general comments about the potential benefits of IRWM in other regions. The American IRWM had a section in which they discussed their relationship to the Sacramento-San Joaquin Delta, but this was more due to the fact that a small portion of the region was located within the Delta, while the section discussed strategies to reduce dependence on Delta water supply. The Kings Basin IRWMP had a general goal of collaborating with neighboring IRWMs on forest management. Outside of IRWMPs, the only mention of interconnection outside the watershed was in Orange Vale Water Company's UWMP. In the section on potential constraints to water sources, they listed the largest threat to their supply as the "political forces that include Southern California, agricultural, Delta, and environmental factions" [67] (p. 19). This was also the only time across all plans that the complicated politics of water management were acknowledged as a threat to water supply.

4.4. Summary

Table 5 summarizes the results for the four watersheds. This shows that the ways in which water management was complex took very different forms across the four watersheds, despite their being located in a similar political, social, and geographic context. There were drastically different numbers of actors in each watershed. Comparing the large American and Kings, both had 50–60 separate organizations managing water; however, the American had 10 times as many water rights holders as in the Kings. The relatively small Shasta and Cosumnes had roughly equivalent numbers of water rights holders as in the Kings; however, they each had far fewer water organizations operating in the watershed (but still a sizeable number). Each watershed also used a very different mix of water sources. For instance, despite the Kings River having a sizeable flow, cities in the region relied almost entirely on groundwater. In the American, which had a similar hydrological availability of surface and groundwater, most organizations used a mix of the two (but relying more heavily on surface water for their regular use). We also saw very different levels of coordination between actors in each watershed, with by far the most occurring in the American. Finally, none of the plans discussed their organization as being situated within a larger watershed.

Table 5. Summarizing watershed characteristics.

	Shasta	American	Cosumnes	Kings
Number of actors	Low	High	Moderate	Moderate
Number of water rights	Few	Numerous	Few	Moderate
Water supply portfolios	Surface	Predominantly surface with some groundwater	Surface and groundwater	Mostly groundwater
Physical interconnections	No interagency purchasing	Diverse networks of interagency purchasing	Minimal interagency purchasing	Almost no interagency purchasing
Level of coordination	Low	High	Moderate	Low to moderate
Stated connection with watershed	Absent	Absent	Absent	Absent

5. Discussion

5.1. Lack of Watershed Scale Management

In this paper, we assessed the current status of water governance in four watersheds in California. We found that in the absence of a single watershed-level authority, governance in the watersheds looked nothing like "watershed management". We expected to find numerous actors in each watershed, but even combined, their activities did not map to the watershed. Coordination between actors did not orient around the boundaries of the watershed, as we saw minimal coordination between the upper and lower parts of the basin. Actors in the headwaters talked to each other, as did actors in the valley, but we never once saw evidence of coordination across this divide (or even written acknowledgement that they were part of the same system). In order to achieve watershed-scale management, connections between the headwaters and the lower watershed would need to be built.

A second challenge in striving toward watershed-scale management relates to the difficulty of defining the boundaries of the watershed [20,50]. Groundwater played an important role in all four watersheds, both as a source or sink for surface water and as a water supply for organizations located in the watershed. However, in no case did the groundwater aquifer coincide with the boundaries of the upper and/or lower watershed. This was most prominent in the American and Cosumnes, as the aquifer that was fed by the American River interacted with the Cosumnes River (at times giving water and at times receiving water), despite the two rivers being in entirely different watersheds (Sacramento vs. San Joaquin). In the Kings and American, there were also cities located outside the watershed that used water—a common phenomenon in the western U.S. Given these characteristics, it was not clear whether the desirable watershed boundary should simply be the surface water hydrologic boundary or should account for groundwater and water exports.

This research thus adds to the literature that suggests that watershed-based management is hard to achieve. Given the very different characteristics of the actors, water supplies, and constraints in each watershed, shifting toward a watershed-scale perspective would require very different institutional changes in each of the four watersheds. For instance, in the Shasta, there was a relatively small number of players, but they could be further embedded in the Klamath Basin and North Coast IRWM, as they currently appeared to play a minor role. Conversely, in the Kings, the connections needed to focus more on recognizing the collective nature of groundwater and its interactions with surface water, as well as on integrating non-water suppliers (like tribes and NGOs) into the conversation. In the American, there were a number of strong networks in place; these could be extended to cover the entirety of the watershed, but the sheer number of actors involved could make them unwieldy. That there was not a single uniform change that would help all watersheds transform to watershed-scale management suggested that it was not a simple institutional design to achieve.

5.2. Implications and Potential Sources of Variation in Complexity and Coordination

We also found varied levels of both physical and institutional complexity and coordination in the four watersheds (Table 5). This was important because, besides helping managers scale up to manage at the watershed level, coordination brought other benefits and challenges for effective governance. Coordination increased transaction costs [68], requiring time and other resources from interacting organizations. When done well, however, it could also help improve the efficiency and effectiveness of governance. It could help the involved organizations achieve economies of scale, access knowledge and resources, and solve the tradeoffs inherent in managing wicked problems [69–72], all potentially helping govern more effectively.

While it was beyond the scope of this paper to assess the effectiveness of the institutional structures observed in each watershed, the literature on coordination and complexity thus suggested that we should see differential performance with respect to water management in the four watersheds. The American watershed had the most actors, the most diverse water supply, and by far the most formal and informal coordination. Thus, despite being more complex, American perhaps had developed the interactions to help manage that complexity. Cosumnes also had decent coordination despite the smaller number of organizations in the watershed. In contrast, the Kings watershed had a similar number of actors, but far lower interorganizational coordination, perhaps reducing effectiveness (though also reducing transaction costs). Lastly, there was minimal evidence of organizations in the Shasta coordinating within the watershed; they only appeared to coordinate with far away organizations through the IRWM process. This would likely increase transaction costs and may not provide many benefits specifically within the watershed.

As for why we saw, the different levels of coordination across watersheds, comparing the American and Kings basins, suggested that it may partially be driven by the different types of physical interconnections. The two watersheds were fairly similar, both in the size of the river and in the population served. However, in the American, the preponderance of interorganizational purchasing made the fact that water was shared very visible; in the Kings, the actors were all drawing from the same aquifer, yet did not acknowledge this as an interdependency. It was perhaps this difference in the visibility of codependence that led to more extensive coordination (both in plan preparation and in the number of water management networks that existed) in the lower American watershed. Griggs noted that regions dependent on surface water evolve very different cultures of water management than those dependent on groundwater, as surface water requires shared infrastructure that therefore requires cooperation [73]; this phenomenon appeared to be playing out here.

6. Conclusions

This paper evaluated the physical and institutional dimensions of water governance in four California watersheds, with the aim of characterizing different types of complexity that arise in watershed governance. As an exploratory study, this project had several limitations that raise interesting opportunities for additional research. First, this research assessed institutions in form, rather than institutions in practice. Coordination on paper did not necessarily imply that an organization had substantive input into a plan. At the same time, we focused only on coordination as related to plan development and dissemination, when there were undoubtedly many other ways that water organizations worked with one another. Thus, we were both over- and under-counting interactions between organizations. By observing coordination activities in practice, we could better understand the types of coordination that were occurring and how they influenced governance effectiveness.

It is also important to note that California water management is evolving quickly with the 2014 passage of the Sustainable Groundwater Management Act (SGMA). Like IRWM, SGMA encourages groups of users that share aquifers to develop plans for achieving sustainable groundwater extraction. Like IRWM, many of the Groundwater Sustainability Agencies that have formed in response fragment aquifers into multiple GSAs; the Kings aquifer has at least four GSAs overlaying it. Thus, there is a new set of organizations and plans that are in the process of layering onto the management system we have described, adding further to the complexity of watershed-based management. As for how SGMA will affect the coordination networks described here, preliminary research suggests that cities and large water agencies are the more dominant actors in SGMA collaborations [74], so it is unlikely that many new actors will be introduced.

Lastly, our findings were also very much shaped by the Californian context. In considering applications outside of California, it is important to note that the average California watershed was likely much more complex and fragmented than what we might see elsewhere. At the same time, the finding that coordination and complexity took different forms in relatively similar watersheds is likely to hold elsewhere, especially in contexts with differing water sources and uses. That said, conducting additional comparative work on the nature and outcomes of watershed-scale governance (with or without a central basin authority) would greatly add value to understanding whether and under what contexts watershed governance is an effective technique, an important task given its common perception as the ideal for management.

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